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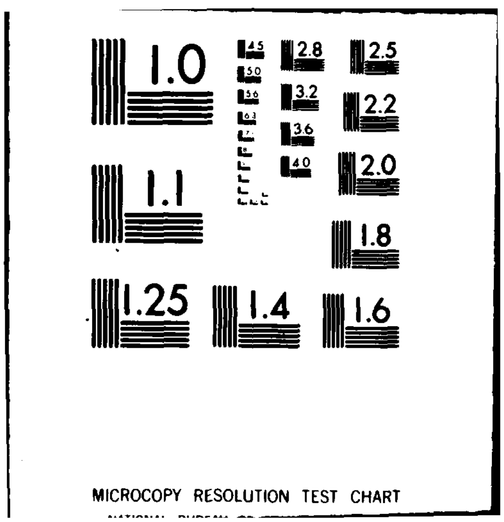
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(6) # Errors in automatic pass point mensuration using digital techniques.

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(10) Michael A. Crombie

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A technique for automatically measuring pass points from digital stereo images is evaluated. Numerical estimates of x-parallax and y-parallax for a specific stereo pair of images is presented as a function of terrain relief.

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PREFACE

This study was conducted under DA Project 4A762707A855, Task B, Work Unit 00016, "Digital Correlation Studies."

The study was done during 1979 under the supervision of Mr. D. E. Howell, Chief, Information Sciences Division; and Mr. L. A. Gambino, Director, Computer Sciences Laboratory.

Special thanks is extended to Mr. Robert S. Rand, ETL, who assisted with the computer programing.

COL Daniel L. Lycan, CE was Commander and Director and Mr. Robert P. Macchia was Technical Director of the Engineer Topographic Laboratories during the study and report preparation.

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ERRORS IN AUTOMATIC PASS POINT MENSURATION USING DIGITAL TECHNIQUES

INTRODUCTION

The Computer Sciences Laboratory has long proposed that digital images of control points be used as a means to register newly acquired digital imagery to a controlled data base. The same idea can be used in pass point mensuration where sidelap images are registered to a previously measured model without needing to reintroduce the first model. If a particular model pass point and its neighborhood were scanned and stored, then the subimage could be displayed for either a visual or automated registration to the sidelap images. In a previous U.S. Army Engineer Topographic Laboratories (ETL) research note,[1] semiautomated pass point mensuration was shown to be more practical than fully automated pass point mensuration, especially in areas of high relief. The purpose of this report is to present estimates of x– and y–parallax error as a function of relief when the pass point is measured both in a fully automated mode and in a supervised mode. The numerical results pertain to a specific model; however, the same procedure can be applied to special images of interest.

MATCH PROCEDURE

The match procedure used in this study is identical to the one suggested in the referenced ETL research note. Two variations of the same procedure were tested. The procedures differed only in how the first estimate of the match point was determined. In the supervised procedure, the operator determines the estimate by pointing to it with the cursor. In the unsupervised procedure, the estimated match point is assigned the same pixel coordinates as those of the corresponding point on the left image. Any point within the 512 x 512 subscene would work as well.

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[1] M. Crombie, *Semi Automatic Pass Point Determination Using Digital Techniques*, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, ETL–0051, December 1975, AD A026 082.

In the first step in either case, the low frequency image information was used to isolate the match point and to reduce the likelihood of a false match. This was done by blurring the scenes to produce an eight times reduction. First, in the upper left corner, each 8 x 8 subarray of pixels was replaced with the average of the 64 gray shades to produce a 64 x 64 blurred image. Next, a 15 x 15 blurred window from the left scene, which was centered on the designated pass point, was moved over the 64 x 64 blurred right scene image to produce an 18 x 18 matrix of correlation values. The match point at this stage was determined to be at the pixel location corresponding to the correlation function maximum.

The second step in either case was a refinement exercise. An N x N window centered over the designated pass point on the fully resolved left image was moved over an (N + 6) x (N + 6) fully resolved subarea of the right image to produce a 7 x 7 correlation function. The subarea from the right image was centered over the match point estimate from the first step. The pixel location associated with the correlation function maximum was designated as a possible match point if the correlation function was concaved downward at the estimate. Next, an (N + 2) x (N + 2) window centered over the designated match point from the left image was moved over an (N + 8) x (N + 8) subarea from the right image to produce a 7 x 7 correlation function. If the new estimate was within 0.1 pixel of the previous estimate and if the correlation function was concaved downward, then the new estimate was designated as the match point. The parameter N was allowed to vary from 3 to 31 in increments of 2.

In the third step in either case, preliminary model parameters were considered. A pass point estimate was rejected if the y–parallax error exceeded 30 μm (micrometers) in absolute value for each y–coordinate. This rejection criterion pertains to a total y–parallax error of 60 μm, or about 2.5 pixel spacings.

In the fourth step in either case, any match point was rejected where the correlation value was less than 0.4.

Twenty-two test regions were selected from a digital stereo model stored in DIAL.[2] A description of the imagery and the scan procedure is given in an ETL report.[3] Nine points within each of the 22 test regions were selected for the pass point analysis. The match points determined by the stereo mapping process were used as control. The test regions are the central portions of the subscenes shown in figures 1, 2, and 3. The three sets of subscenes are designated as smooth, moderate and steep. The designations pertain to terrain relief and were determined in the following way. The average slope (in degrees) was determined over each region by using the 400 elevations determined from stereo matching. A matrix of 25 elevations about each of the 9 test points within each of the 22 test regions was used to obtain a measure of terrain roughness. The terrain roughness, σ_T (in meters), is the pooled standard deviation associated with the 9 test points. The terrain relief designations were defined in the following way:

TEST MODEL

$$\text{Smooth:}\quad 0^\circ < |\text{ Slope }| \leq 10^\circ$$
$$\text{Moderate:}\quad 10^\circ < |\text{ Slope }| \leq 15^\circ$$
$$\text{Steep:}\quad 15^\circ < |\text{ Slope }|$$

A summary of the test model is presented in table 1. The column labeled σ_{ST} (micrometers) pertains to the y-parallax estimates determined from intersection using the stereo match results. The columns labeled **Location** pertain to region locations as defined in an ETL report.[4]

[2] L. Gambino and B. Schrock, "An Experimental Digital Interactive Facility," *Computer*, August 1977, pp. 22–28.

[3] M. Crombie, *Stereo Analysis of a Specific Digital Model Sampled from Aerial Imagery*, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, ETL–0072, September 1976, AD–AD033 567.

[4] Ibid.

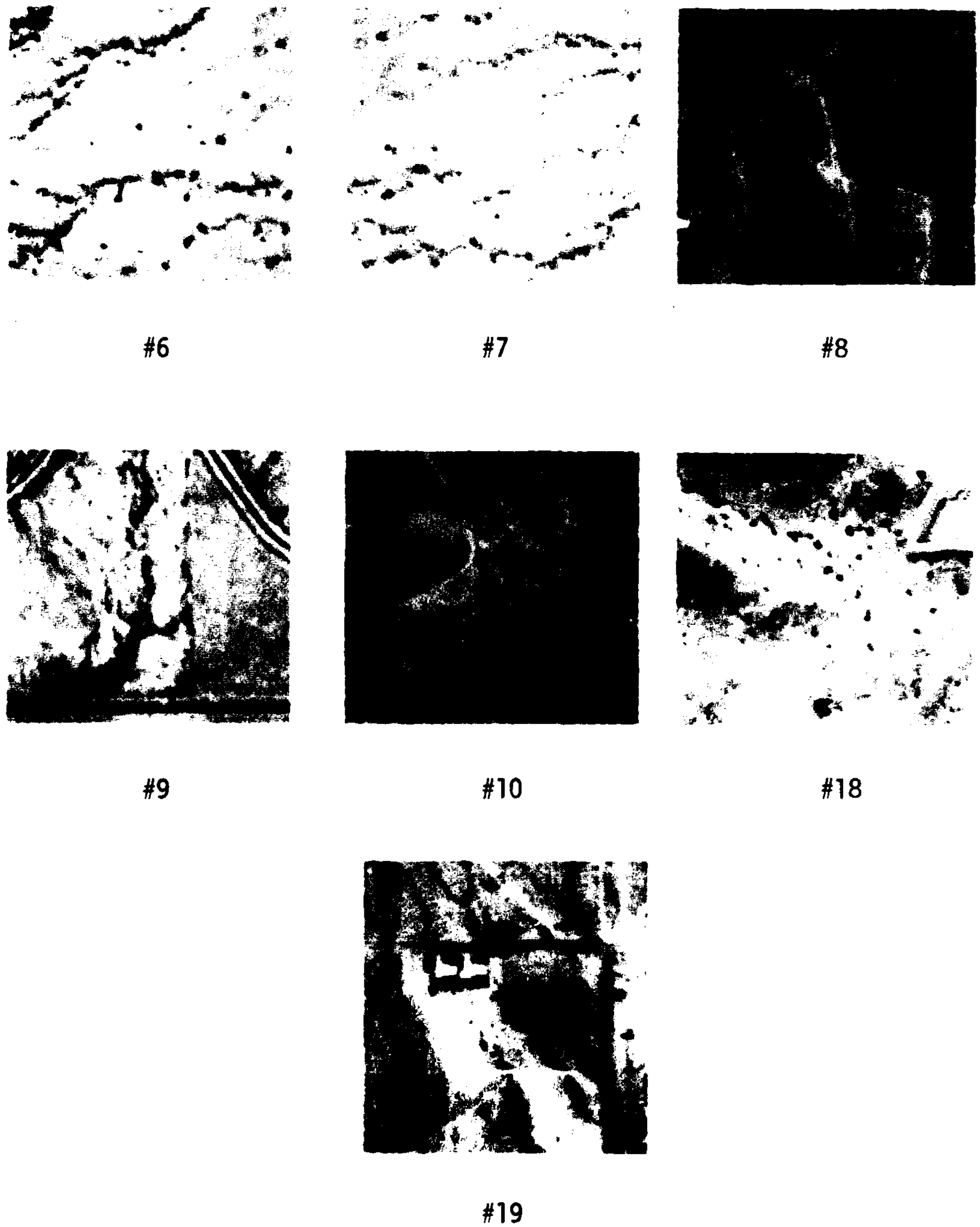

FIGURE 1. Test Regions – Smooth Terrain.

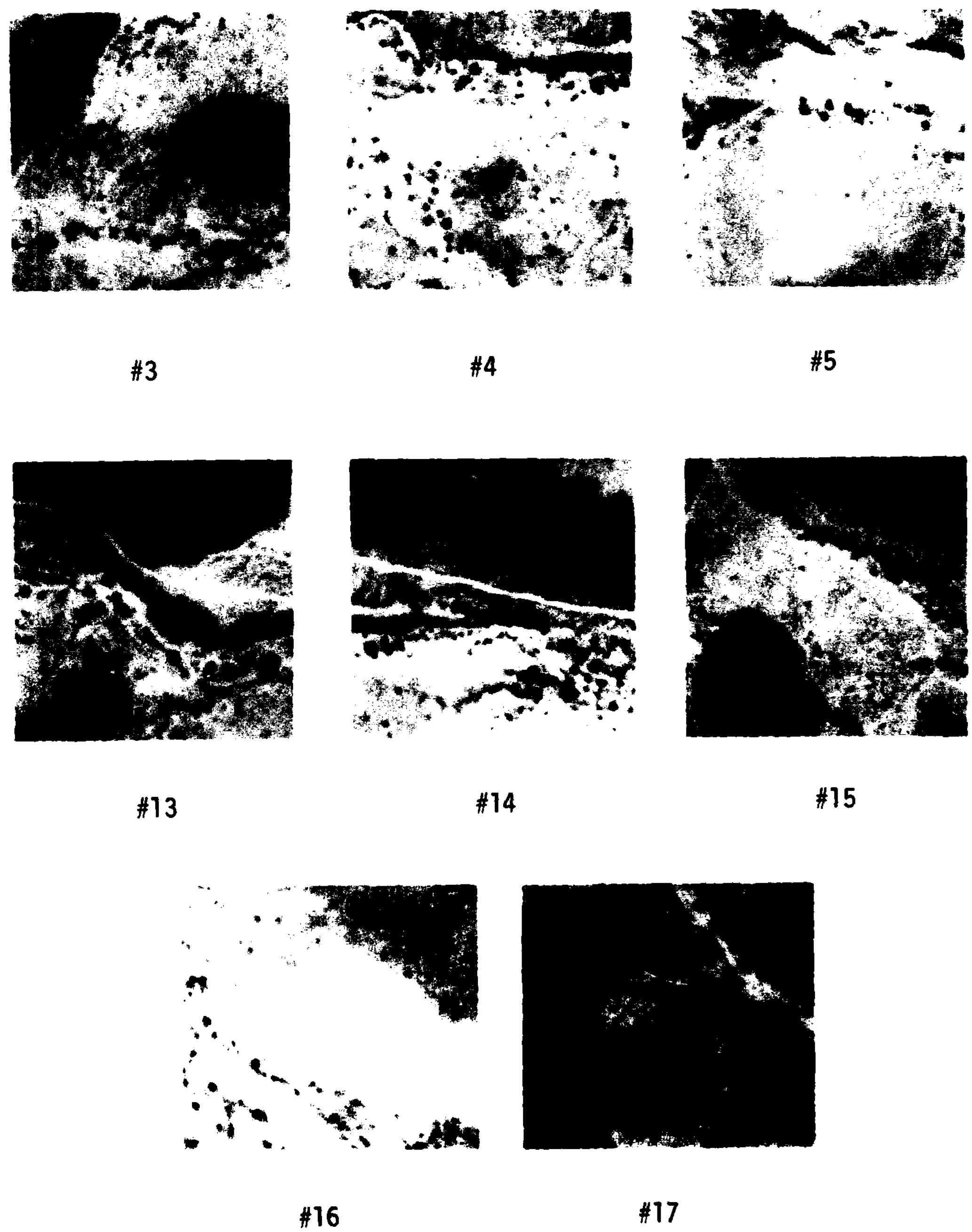

FIGURE 2. Test Regions — Moderate Terrain.

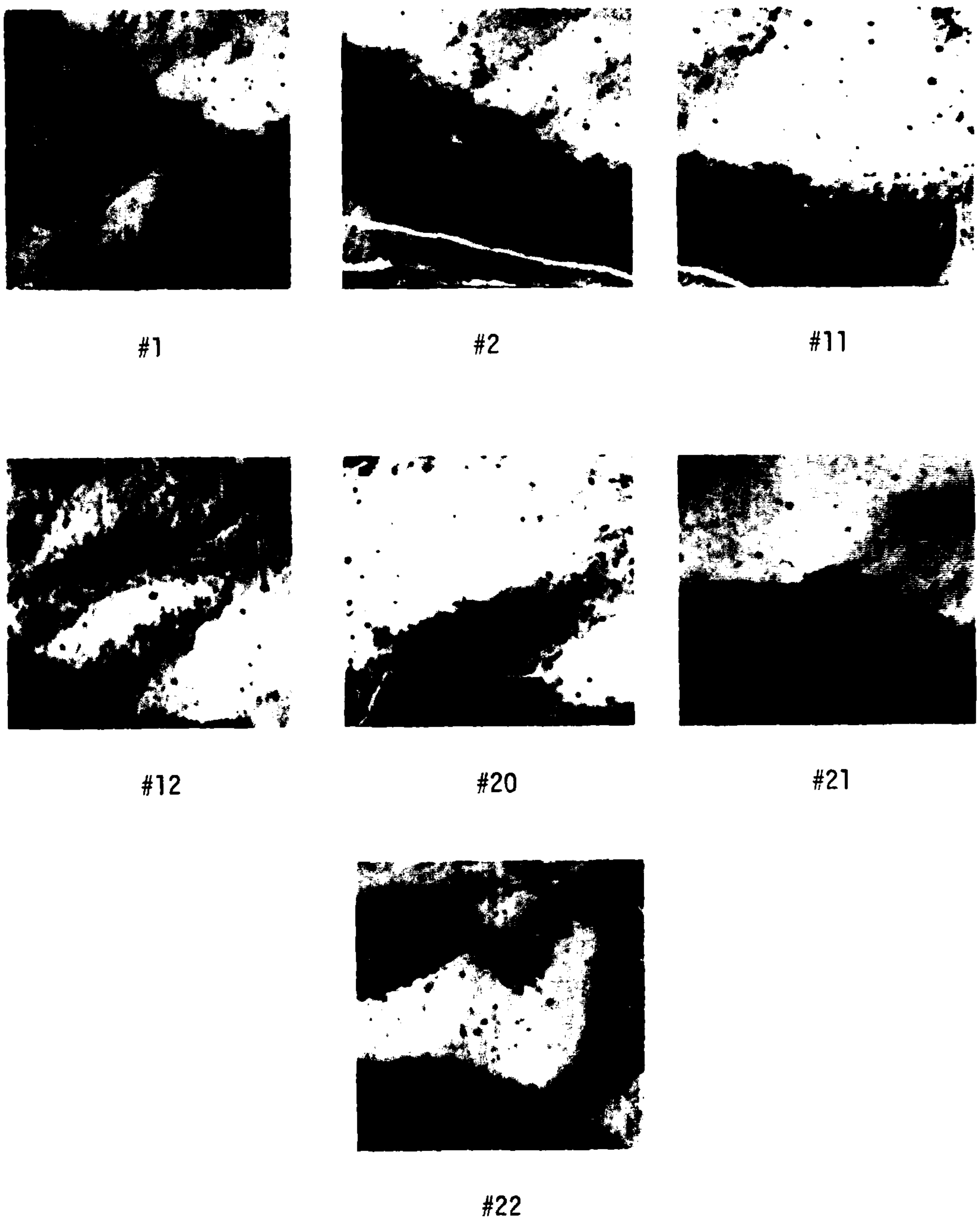

FIGURE 3. Test Regions – Steep Terrain.

TABLE 1. Test Model Statistics

Region	Slope	σ_T	σ_{ST}	Location Block	Location File	Region
1	20.6	3.9	1.2	2	3	Steep
2	20.6	4.0	3.0	3	6	Steep
3	11.4	2.5	2.0	7	8	Moderate
4	12.7	1.9	2.1	5	4	Moderate
5	12.5	3.6	3.1	7	12	Moderate
6	5.2	0.9	2.0	4	14	Smooth
7	4.6	0.7	2.5	4	16	Smooth
8	8.9	1.4	2.8	16	3	Smooth
9	6.0	0.8	11.7	19	10	Smooth
10	5.2	0.8	4.9	18	8	Smooth
11	19.0	4.2	3.6	3	8	Steep
12	15.8	3.2	3.1	2	7	Steep
13	11.6	2.1	2.6	5	8	Moderate
14	13.4	2.8	1.5	4	6	Moderate
15	11.4	2.1	3.0	15	5	Moderate
16	14.8	3.1	3.5	13	8	Moderate
17	12.7	2.5	4.0	11	6	Moderate
18	7.5	1.2	7.4	13	17	Smooth
19	10.0	1.8	10.9	17	14	Smooth
20	31.2	9.5	2.6	8	12	Steep
21	20.7	4.0	4.0	9	14	Steep
22	15.1	3.1	1.0	9	3	Steep

The x–parallax errors were estimated by regarding the elevations from stereo matching exercise as control. Differences in elevations were converted into x–parallax estimates by using the following formula:

NUMERICAL RESULTS

$$\sigma_x \simeq \frac{(B/H)^*\sigma_h}{(H/_f)} = \frac{0.6\ \sigma_h}{47000} = 12.77\sigma_h$$

σ_h: Sample standard error from elevation differences (meters)

(B/H): Base–Height of Model

$H/_f$: Scale of Photography

σ_x: x–parallax estimates (micrometers)

The numerical results are presented in tables 2 through 6. The tables are organized by relief designation and by the correlation rejection criterion. Note that all of the valid matches of the smooth terrain had correlation values greater than 0.4. The entries in the columns labeled **R** are the averages of the region correlation values. The entries in the column labeled **df** are the degrees of freedom associated with the estimates. Also note that if in the match refinement process the window size reached 31 without satisfying the match criterion, then the process was halted and a match failure was indicated. For most of the satisfactory matches the final match window size was 13.

TABLE 2. Smooth Terrain Results (R > 0.0)

Supervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
6	11.3	10.4	.83	9	11.3	10.4	.83	9
7	5.0	4.1	.68	9	5.0	4.1	.68	9
8	6.4	5.2	.64	9	6.4	5.2	.64	9
9	8.7	4.2	.71	9	8.7	4.2	.71	9
10	26.2	38.0	.77	9	13.9	4.3	.81	8
18	7.9	5.0	.80	9	7.9	5.0	.80	9
19	30.7	6.9	.73	8	10.7	7.5	.73	7

Unsupervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
6	12.8	10.9	.83	9	12.8	10.9	.83	9
7	5.8	5.1	.68	9	5.8	5.1	.68	9
8	6.4	5.2	.64	9	6.4	5.2	.64	9
9	8.7	4.2	.71	9	8.7	4.2	.71	9
10	26.2	38.0	.77	9	13.9	4.3	.81	8
18	7.9	5.0	.80	9	7.9	5.0	.80	9
19	30.7	6.8	.73	8	10.8	7.3	.73	7

TABLE 3. Moderate Terrain Results ($R > 0.0$)

Supervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
3	5.5	9.6	.74	9	5.5	9.6	.74	9
4	5.6	14.6	.75	9	5.6	14.6	.75	9
5	30.4	37.3	.59	9	9.2	11.8	.61	7
13	2.9	10.4	.81	9	2.9	10.4	.81	9
14	3.0	7.6	.76	9	3.0	7.6	.76	9
15	31.7	51.4	.61	9	6.4	10.1	.63	8
16	39.1	33.4	.56	9	11.9	19.0	.60	7
17	10.1	12.3	.75	9	10.1	12.3	.75	9

Unsupervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
3	5.5	9.6	.74	9	5.5	9.6	.74	9
4	5.6	14.6	.75	9	5.6	14.6	.75	9
5	30.0	134.4	.61	7	20.9	11.3	.63	5
13	3.6	10.4	.79	9	3.6	10.4	.79	9
14	3.0	7.6	.76	9	3.0	7.6	.76	9
15	30.9	55.6	.61	9	6.8	10.8	.62	8
16	23.4	18.2	.56	7	9.6	19.5	.59	6
17	10.8	15.5	.74	9	10.8	15.5	.74	9

TABLE 4. Moderate Terrain Results ($R > 0.4$)

Supervised Initial Estimate

Region	No Model σ_y	No Model σ_x	No Model R	No Model df	Model σ_y	Model σ_x	Model R	Model df
3	5.5	9.6	.74	9	5.5	9.6	.74	9
4	5.6	14.6	.75	9	5.6	14.6	.75	9
5	27.0	42.5	.73	6	10.8	12.4	.74	5
13	2.9	10.4	.81	9	2.9	10.4	.81	9
14	3.0	7.6	.76	9	3.0	7.6	.76	9
15	31.7	51.4	.61	9	6.4	10.1	.63	8
16	34.9	35.7	.58	8	11.9	19.0	.60	7
17	10.1	12.3	.75	9	10.1	12.3	.75	9

Unsupervised Initial Estimate

Region	No Model σ_y	No Model σ_x	No Model R	No Model df	Model σ_y	Model σ_x	Model R	Model df
3	5.5	9.6	.74	9	5.5	9.6	.74	9
4	5.6	14.6	.75	9	5.6	14.6	.75	9
5	28.6	45.9	.76	5	8.7	12.7	.78	4
13	3.6	10.4	.79	9	3.6	10.4	.79	9
14	3.0	7.6	.76	9	3.0	7.6	.76	9
15	30.9	55.6	.61	9	6.8	10.8	.62	8
16	9.6	19.5	.59	6	9.6	19.5	.59	6
17	10.8	15.5	.74	9	10.8	15.5	.74	9

TABLE 5. Steep Terrain Results (R > 0.0)

Supervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
1	4.8	7.4	.65	8	4.8	7.4	.65	8
2	8.7	10.4	.62	9	8.7	10.4	.62	9
11	25.1	20.2	.60	9	11.7	13.2	.63	8
12	12.4	25.8	.61	9	12.4	25.8	.61	9
20	37.8	44.7	.53	8	6.8	30.4	.62	5
21	26.9	19.7	.53	9	9.8	7.3	.55	8
22	29.8	26.2	.66	9	6.9	27.9	.64	8

Unsupervised Initial Estimate

	No Model				Model			
Region	σ_y	σ_x	R	df	σ_y	σ_x	R	df
1	79.1	119.3	.56	8	5.5	52.2	.61	7
2	8.8	10.0	.63	7	8.8	10.0	.63	7
11	26.3	22.2	.61	7	6.7	13.8	.65	6
12	14.2	27.8	.59	7	14.2	27.8	.59	7
20	88.0	248.9	.51	9	5.2	158.5	.56	5
21	34.5	101.3	.56	8	9.9	76.2	.56	7
22	6.5	30.0	.68	9	6.5	30.0	.68	9

TABLE 6. Steep Terrain Results ($R > 0.4$)

Supervised Initial Estimate

Region	No Model σ_y	No Model σ_x	No Model R	No Model df	Model σ_y	Model σ_x	Model R	Model df
1	4.8	7.4	.65	8	4.8	7.4	.65	8
2	6.5	10.7	.66	8	6.5	10.7	.66	8
11	12.2	15.0	.72	6	12.2	15.0	.72	6
12	12.4	25.8	.61	9	12.4	25.8	.61	9
20	21.2	29.2	.59	6	6.8	30.4	.62	5
21	11.1	8.2	.68	5	11.1	8.2	.68	5
22	31.5	27.7	.70	8	6.9	27.9	.71	7

Unsupervised Initial Estimate

Region	No Model σ_y	No Model σ_x	No Model R	No Model df	Model σ_y	Model σ_x	Model R	Model df
1	4.2	4.5	.64	6	4.2	4.5	.64	6
2	5.7	8.1	.68	6	5.7	8.1	.68	6
11	4.5	15.3	.64	5	4.5	15.3	.64	5
12	14.2	27.8	.59	7	14.2	27.8	.59	7
20	74.9	130.4	.68	5	8.8	10.1	.72	3
21	43.2	104.5	.71	5	11.0	8.6	.74	4
22	6.5	32.1	.72	8	6.5	32.1	.72	8

DISCUSSION

The purpose of this study was to determine x– and y–parallax errors as a function of relief when a pass point is measured in a supervised mode and in an unsupervised mode. In addition, the processes were controlled by requiring that model geometry be satisfied when model geometry is known and/or by requiring that the correlation value associated with the match be above a given threshold. In this experiment, the threshold value for correlation was 0.4, and the model requirement was that the total y–parallax error be less than 60 μm. The results presented in tables 2 through 6 are statistically averaged and presented in more concise form (tables 7, 8, and 9). The tabular entry N pertains to the total number of attempted matches.

From the tabular entries pertaining to df, the number of successful matches associated with the particular operation are indicated, which then can be compared to the total number of attempted matches. For example, in steep terrain, when an unsupervised mensuration is performed with model and correlation constraints, then only 39 matches are regarded as acceptable. This corresponds to a 40 percent rejection rate with and x–parallax error of 20 μm. If the mensuration is supervised, then 48 matches are regarded as acceptable. This corresponds to a 25 percent rejection rate with no change in x–parallax error.

It can be seen from the tables that model control is necessary, especially in moderate and steep terrain, if the x–parallax error is to remain below 20 μm. In fact, an unsupervised mensuration with model control, but no constraint on R, produces an x–parallax error of 64 μm in steep terrain. In areas of low relief, supervised as well as unsupervised matching can produce corresponding image points with x–parallax errors less than 16 μm (see table 7). If a model constraint is introduced, then the x–parallax error is less than 9 μm.

TABLE 7. Summary of Smooth Terrain

N = 63

	R > 0.00				R > 0.40			
	Supervised		Unsupervised		Supervised		Unsupervised	
	No Model	Model	No Model	Model	No Model	Model	No Model	Model
σ_y	16.4	9.4	16.6	9.7	16.4	9.4	16.6	9.7
σ_x	15.6	6.2	15.7	8.5	15.6	6.2	15.7	8.5
R	0.74	0.73	0.74	0.73	0.74	0.73	0.74	0.73
df	62	60	62	60	62	60	62	60

TABLE 8. Summary of Moderate Terrain Results

N = 72

	R > 0.00				R > 0.40			
	Supervised		Unsupervised		Supervised		Unsupervised	
	No Model	Model	No Model	Model	No Model	Model	No Model	Model
σ_y	21.3	7.3	18.1	8.8	13.9	7.4	15.1	6.9
σ_x	26.9	12.2	49.0	12.7	27.2	12.2	24.4	12.8
R	0.70	0.71	0.70	0.71	0.72	0.73	0.72	0.72
df	72	67	68	64	68	65	65	63

TABLE 9. Summary of Steep Terrain Results

N = 63

	R > 0.00				R ⩾ 0.40			
	Supervised		Unsupervised		Supervised		Unsupervised	
	No Model	Model	No Model	Model	No Model	Model	No Model	Model
σ_y	23.6	8.8	49.8	8.7	16.8	9.1	30.7	8.6
σ_x	24.5	15.9	118.4	64.2	20.2	19.9	60.3	20.2
R	0.60	0.62	0.59	0.62	0.66	0.66	0.67	0.67
df	61	55	55	48	50	48	42	39

CONCLUSIONS

It is concluded that 1. Model control is necessary for automatic pass point mensuration in moderate and high relief. 2. A correlation value of 0.40 or greater is necessary for a successful match in steep terrain. 3. Automatic pass point mensuration is feasible in areas of low relief.